Active Noise Reduction: Can you really be within one percentage point of perfection?

Dr. Paul Darlington, Chief Acoustic Scientist, Phitek Systems Ltd.

Many readers will be familiar with headphones which feature Active Noise Reduction (ANR) technology. These devices have matured from their origins within military communications in the 1980s to become a significant subset of the contemporary personal audio market. Today the headphones are joined by an increasing number of in-ear devices (earphones or, as some manufacturers choose to call them, “in-ear headphones”) also offering active noise reduction functionality.

There has long been discussion about how best to assess the performance of these devices, particularly as some aspects of their function make the standardized tests for passive hearing protectors inappropriate for use with active devices. This discussion is complicated when we extend the scope to ask how we might report performance to the consumer, for whom engineering metrics—particularly the deciBel—convey little meaning.

Over the past few months, an increasing number of ANR personal audio products are being marketed accompanied by claims of 99% noise reduction on retail packaging or in published technical specifications. When any technology is claiming to be within 1% of perfection, surely it is time to celebrate that technical achievement—or question the claim!

This note takes a look at the claim of 99% noise reduction, tracing its (entirely justified) engineering origins, but questioning its appropriateness as an indication of utility, and value, to the customer.

To borrow a word from one of the manufacturers who currently choose to represent their product in this way: What is “astonishing” about the 99% noise reduction figure arises from the translation of an attenuation measurement in deciBels into a more publicly accessible language. Before we consider this translation, let’s take a moment to remind ourselves of some of the properties of the deciBel:

**Background – the deciBel**

There exists a unit of engineering measurement called the Bel, honouring Alexander Graham Bell, which is defined as the base ten logarithm of an energy ratio. Unfortunately, the Bel is a rather coarse unit for many applications (although, as we shall see later, it does have a particular relevance to the perception of loudness) so we tend to chop it up into smaller, more manageable pieces, by using the deciBel.

This deciBel is defined as ten times the base ten logarithm of an energy ratio. Note the use of an upper-case “B” for the Bel (just as we honour Volta, Ampère, Joule, Coulomb, Watt and the other giants on whose shoulders we stand by capitalizing the first letter of their eponymous units) and a lower-case metric prefix “deci” – we should write “deciBel” and “dB”, just as we would write “milliVolt” and “mV”.

So, given an energy ratio $E_1/E_2$, we can represent that ratio in deciBels using the expression:
In acoustics, just as in electronics, it is unusual to instrument energy directly. In electronics, we would naturally instrument voltage (which is a measure of energy per unit charge, J/C) and in acoustics it is similarly convenient to instrument pressure (which is a measure of energy density, J/m$^3$). In translating these primary measurands into energies or energy ratios (suitable for use in the deciBel expression above) we end up squaring the voltage or pressure. These squared variables are proportional to POWER which can be integrated over time to produce an equivalent energy – in other words energy is proportional to the mean squared voltage in an electronic application and to mean squared pressure in an acoustic application.

So, given a voltage ratio, $V_1/V_2$ or a pressure ratio, $p_1/p_2$, (in which $V$ and $p$ are understood to be Root Mean Square values in an a.c. application) we can represent those ratios as deciBels using the expressions:

$$10 \log_{10} \left( \frac{E_1}{E_2} \right) \text{ deciBels}$$

Readers will recall that, through the defining property of logarithms log(a*b)=log(a)+log(b), we can write the expressions above in the form:

$$20 \log_{10} \left( \frac{V_1}{V_2} \right) \text{ deciBels} \quad \text{and} \quad 20 \log_{10} \left( \frac{p_1}{p_2} \right) \text{ deciBels}$$

So – a noise cancelling product which reduces a pressure $p_1$ to a lower pressure $p_2$ delivers an active attenuation of

$$\text{Attenuation} = 20 \log_{10} \left( \frac{p_1}{p_2} \right) \text{ dB}$$

Having refreshed our memories, we’re now in a position to consider the relationship between dBs and a percentage formation of the ratios they describe. Let’s suppose that a particular active noise reducing product offers the (typical) active noise reduction of 20dB – this means that the energy is reduced by a 100:1 ratio:

$$10 \log_{10} \left( \frac{E_1}{E_2} \right) = 10 \log_{10} \left( \frac{100}{1} \right) = 20\text{dB}$$

If the energy after noise reduction is 1% of the original energy then the system must have cancelled 99% of that original energy—the 99% claim is fully justified in terms of energy. It is simple to construct a relationship between attenuation in dB and equivalent percentage reduction in energy and to graph it, Figure 1:
Percentage reduction (energy) = \(100 \times \left(1 - 10^{-\left(\frac{-\ast\text{attenuation}}{10}\right)}\right)\)

Notice that once 20dB attenuation is reached, this metric has very little available “resolution” to differentiate between products offering slightly different attenuations—we will be into arguments about fractions of a percent!

As was observed previously, it is unusual to instrument energy directly in acoustics or electronics, making the formulation above somewhat unusual (indeed, it is difficult to avoid a suspicion of bias). More naturally, engineers might choose to describe an active control system’s action in attenuating that primary variable which they (and it) observe—in this case, pressure.

Using such an alternative strategy, an active noise reduction system achieving 20dB attenuation would still deliver the 100:1 energy ratio, but this would be associated with a pressure ratio of 10:1 (remember: energy is proportional to SQUARED pressure).

If the pressure after noise reduction is 10% of the original energy, then the system must have cancelled the other 90% of that original pressure—the 99% claim in terms of energy is exactly equivalent to a 90% reduction in terms of pressure. It is simple to construct a relationship between attenuation in dB and equivalent percentage reduction in pressure and to graph it, Figure 2 (we leave the percentage energy trace of the previous graph visible as reference).

Percentage reduction (pressure) = \(100 \times \left(1 - 10^{-\left(\frac{-\ast\text{attenuation}}{10}\right)}\right)\) %
Notice that these two methods of reporting performance are entirely legitimate from an engineering perspective.

However, the “percentage pressure” reduction does leave greater opportunity to resolve differences between products without resorting to decimal places of percentage values. Note also that in the range of active attenuations typical of current product (10 - 30 dB), the two measures return significantly different numerical values.

At the time of writing, manufacturers are using both of these methods to report noise reducing performance, with the result that the consumer is not able to make informed choices on a level playing field; rather, they are comparing apples with oranges! Those opting to use the “energy” formulation are deliberately choosing a method which returns a higher and more attractive figure, yet only some of these manufacturers are explicit in declaring (in the small print) that this figure is associated with the reduction of energy.

We have spoken about figures arising from the measurement of objective phenomena within these noise cancelling products, but we have so far managed to ignore the subjective issue of how these devices are perceived by their owners. To do this, we must consider human perception of sound.

When a customer buys a noise cancelling product, they are little concerned with the percentage reduction of energy or pressure. They are concerned with how much quieter the noise is as a result of the active noise reduction system. The subjective judgement of “how much quieter” is best understood with reference to the perception of loudness, we must take a detour into psychophysics:
Background – a little Psychoacoustics

The perceived loudness of a sound is a very complex, non-linear, frequency-dependent function of the objective sound stimulus. To simplify matters, we shall adopt a naive but adequate model of the loudness percept.

Gustav Fechner postulated in the mid-19th century that sensations are proportional to the logarithm of the intensity of the stimulus that evokes them (in what came to be known as Fechner’s law—or the Weber-Fechner law). Although this work was later discredited in certain applications (giving way to “Power law” models of the sort proposed by Stanley Stephens in the middle of the 20th century), Fechner’s law is still instructive in the case of the perception of loudness.

The loudness of a simple sound presented at comfortable amplitudes well within the ordinary audible frequency range is found to closely approximate a logarithmic function of the intensity of the sound. Rather than doubling with a doubling of pressure, loudness has been observed to double roughly with a 10dB increase in the stimulus (a √10-fold increase in pressure). Notice that this is one Bel—so the Bel corresponds to an approximate 2-fold change in loudness. For more context, the deciBel is rather close to the Just-noticeable-difference (‘JND’) limit in amplitude at which people can just detect a change in loudness.

We can easily remember this approximate loudness model—a 1dB change in sound is just perceptible as a change in loudness, whilst a 1B (10dB) increase is perceived as a doubling of loudness.

In our application, an active noise reducing device offering 20dB attenuation (which, as we have already seen, corresponds to a 99% reduction in energy and a 90% percent reduction in pressure) would give 2 Bels worth of “loudness halving”. This is a reduction of 75% in loudness (100*[1-(1/2 * 1/2)] = 75). We can build a general expression for percentage reduction in loudness as a function of attenuation in dB and graph it, Figure 3 (again, we’ll leave the percentage reduction traces of the previous graphs visible as reference).

Percentage reduction (“loudness”) = 100 * (1 − \( \frac{\text{attenuation}}{10} \))^2

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Figure 3: Percentage reduction in loudness as a function of attenuation in dB

Notice again that this metric, derived from consideration of a simple model of the loudness percept, returns a very different “percentage reduction” figure from the previous “objective” measures. At the time of writing, I know of no manufacturer using the third of these measures to report ANR performance, yet I suspect it is a better correlate of user experience than either of the two methods in use.

An Example from a Different Sector

In previous consulting work for a manufacturer of sheet material produced as an underlay for wooden flooring, I measured a “Weighted Impact Sound Reduction Index” of 19dB. This figure describes the attenuation of the sound of footfalls on a floor equipped with the underlay propagating down to a listener in a room on the level below.

The company sold direct to the public through home improvement stores and wished to find a way to explain the significance of the 19dB figure.

On hearing that the 19dB reduction corresponded to a 98.4% reduction in transmitted energy, the owner of the company immediately said “we can’t put that on our advertising – the public will never believe it”.

The company adopted the “percentage reduction of loudness” proposed above and used it on their product packaging.
At risk of sounding cynical, it is perhaps obvious which of these three metrics will be selected by marketing people anxious to present their product in the best possible light. It is equally obvious that a potential purchaser will find a 99% claim difficult to ignore if a similar (potentially identical) offering is described as delivering only 75% reduction. Perhaps the morality of marketing is an issue which should be left to trouble marketing practitioners in the small hours. There remains, however, one legitimate concern for all of us.

The performance metrics discussed here do more than inform purchasing decisions, they establish expectations for the technology. If an ordinary member of the public sees a claim for 99% reduction of unwanted noise, they naturally expect that which is left to be close to silence. If the product doesn’t deliver that perceived benefit, they will be dissatisfied.

It is the easiest thing in the word to hype or oversell a technology, and we all recognize the potential consequences of doing this. Implying that contemporary commercial Active Noise Reduction systems achieve performance within one percentage point of perfection risks disappointing customers and damaging the technology.

Surely this is in the interests of neither the consumer, nor the manufacturers?

About the author

About Phitek Systems Limited
Phitek Systems (Auckland, New Zealand) is a leading supplier of electro-acoustic technologies for audio enhancement and active noise cancellation. Focused on innovation and invention, Phitek provides global customers with creative solutions for the effective reduction of ambient noise based on its patented Active Noise Rejection (ANR™) technology, originally developed for use in commercial passenger aircraft where background noise is insidious leading to hearing loss, fatigue and stress. Today, Phitek ANR™ is used by more than 50 airlines worldwide, servicing more than 15 million passengers each year. The technology works by measuring the noise field close to the ear and then calculating an “antinoise” response which is sent to the headphone speaker.